Chapter

New Frontiers in Flood Risk Management

Guangwei Huang

Abstract

Flood risk management has been studied extensively and intensively in many academic fields from civil engineering, sociology, economics, culture, and even psychology. However, the fact that flooding accounts for a greater number of damaging events than any other type of natural events worldwide on an yearly scale proves that our understanding of flooding is still insufficient, flawed, and fragmented. This chapter intends to shed new light on a number of issues that deserve more comprehensive study in order to advance flood risk management. As a result, a new two-layer framework of vulnerability is proposed, which can lead to a better understanding of, and new approaches to, flood risk management.

Keywords: vulnerability, framework, flooding time, flood duration, Ec0-DRR

1. Introduction

Flood disaster management includes flood risk assessment, risk mitigation, preparedness, and emergency response and rehabilitation efforts. It can also be classified into before, during, and after event activities. A flood risk assessment is an assessment of the risk of flooding from all flooding mechanisms and consists of three components: (1) hazard identification, (2) vulnerability analysis, and (3) exposure assessment. Mathematically, it can be expressed:

$$\text{Risk} = \text{Hazard} \times \text{Vulnerability} \times \text{Exposure} \quad (1)$$

According to UN-ISDR [1], hazard can be defined as a dangerous phenomenon, substance, human activity, or condition that may cause loss of life, injury or other health impacts, property damage, loss of livelihoods and services, social and economic disruption, or environmental damage. It can be quantified by a probability of occurrence within a specified period of time and within a given area and given intensity. The term exposure is used to indicate elements subject to potential damage due to a hazard. Elements here may be referred to population, houses, facilities, or physical and life infrastructure essential to the functioning of a society or community such as water supply system.

There are many aspects of vulnerability, related to physical, social, economic, and environmental conditions (see, for example, Birkmann [2]). Therefore, vulnerability can be defined in a number of different ways from as simple a notion as the degree of damage to an object exposed to a given hazard, to a more sophisticated one such as the characteristics and circumstances of a community, system, or asset that make it susceptible to the damaging effects of a hazard. Thus, the choice of definition may depend on its suitability for a particular vulnerability study and its interpretation for policy or action. The fact that it can be approached in manifold ways offers both flexibility and difficulty to use and interpret.

Villagran de Leon proposed a different framework of risk, which consists of hazard, vulnerability, and deficiencies in preparedness [3]. Exposure was treated as a component of the hazard. The term "deficiencies in preparedness" was used to emphasize the lack of coping capacities of a society at risk. The pressure and release model [4] considers disaster as a product of two major forces: natural hazard and vulnerability. It was intended to stress the importance of vulnerability assessment.

No matter what framework one employs to deal with vulnerability and risk, the assessment should go beyond the identification of vulnerability and risk. It should probe into underlying driving forces and root causes in order to reduce or minimize them.

The objective of the present study is to highlight a number of shortcomings in conventional frameworks for flood risk management. A focal point is the framework for vulnerability.

2. Shortcomings in conventional frameworks

2.1 Hazard component related

Flood hazard is conventionally described by its probability of occurrence and severity (magnitude, duration, and extent of flooding). However, evidence has been mounting that the timing of a flood really matters. On July 7, 2018, Mabi town in Okayama Prefecture, Japan, near the confluence of the Takahashi River and the Odagawa River, was inundated due to levee breaches in the two rivers. As shown in **Figure 1**, the highest water level in the Takahashi River near the river junction occurred at 3:00 AM and exceeded the historical records. In this disaster, more than 50 people perished with 90% of the victims aged from 66 to 91. These elders lived either alone or with a senior spouse. For elders, evacuation during the night is difficult both physically and mentally. Besides, there were media reports and our own interviews heard the same story from people who suffered from inundation in various places in recent years that flood waters entering their homes rose so quickly that they had difficulty to escape. Therefore, inundation is not just a matter of

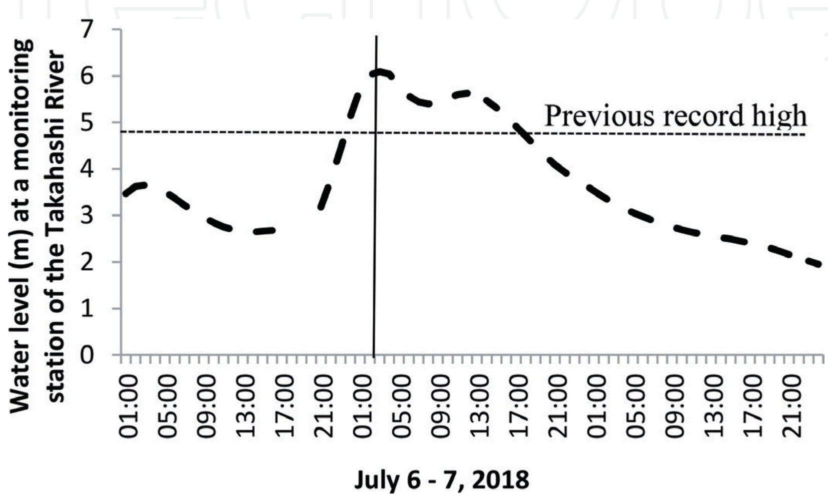

Figure 1.
Hydrograph of the Takahashi River, Japan, on July 7, 2018, that peaked at 3:00 AM.

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depth but also the rate of rising. The rate of inundation depth increase may depend on many factors such as local topography, the presence of structures, and urban drainage systems as well. So far, there is little information on the variation patterns of inundation depth with time during flood disasters. How fast the inundation depth would increase should be given serious consideration in flood risk management plans.

Figure 2 shows the comparison of rising limb of hydrography at the Sakazu hydrological station between the largest-ever flood of the Takahashi River occurred in 2018, the second largest flood in 2011, and a small flood in 2015. It is clearly seen that the rate of water level increase depended on the intensity of a flood. The larger the intensity, the fast the water level increased. The current flood warning system in Japan is based on four water levels: (1) stand-by level, (2) flood watch level, (3) flood alert level, and (4) flood danger level. Such a warning system is essential for emergency evacuation. However, a problem with this system is that information on how fast the water level may rise from one level to another in an unprecedented flood is not available because it is intensity dependent as shown in **Figure 2**. How to provide real-time forecast on water level rising speed and incorporate it into the warning system is a technical issue to be explored. Besides, a related question is: is there a link between the rate of water level increase in channel and the temporal variation pattern of inundation depth in flooded area? It is also question deserving in-depth study.

On July 30 2011, the Ikarashi River in Niigata Prefecture, Japan, breached around 5:00 AM. In addition to the timing of inundation, other characteristics of this flood can be described as having two consecutive floods or a two-peak hydrological event. For the first peak, a dam in the upstream of the river regulated the peak, but for the even larger second peak, the dam failed to function since it was already at capacity.

These pieces of evidence serve to demonstrate that hazard identification should include flood peak timing and the possibility of multipeaks in addition to probability and magnitude. However, methodology to consider these factors has not been developed.

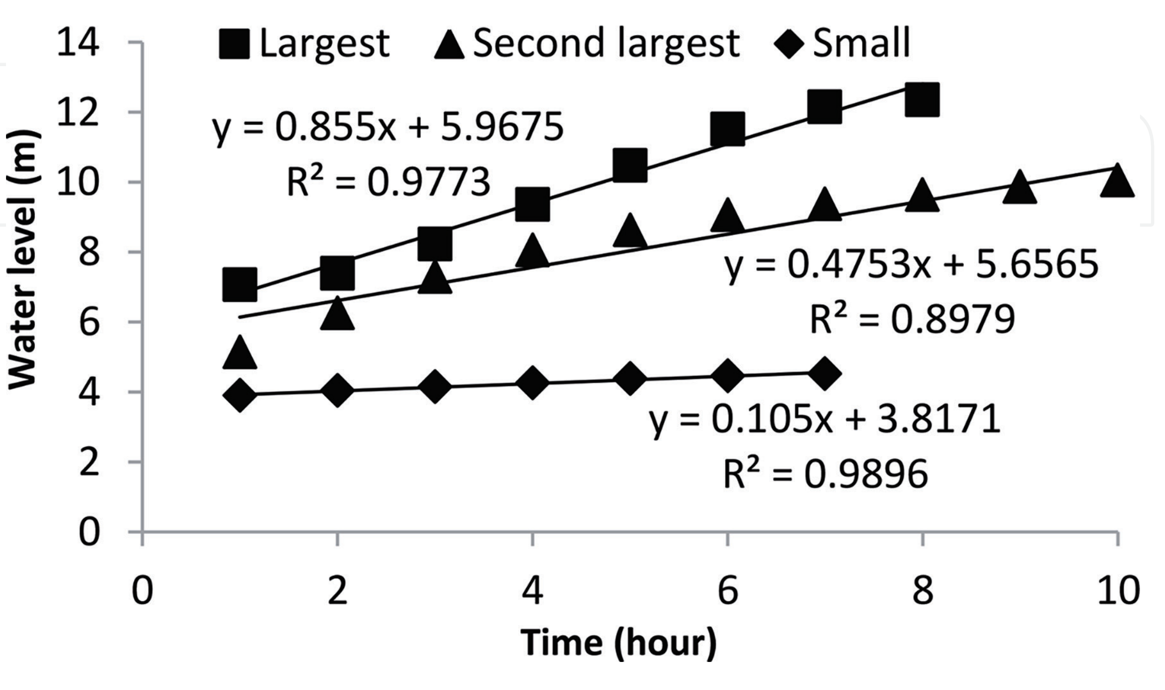

Figure 2.
Intensity dependency of flood water level rising rate.

2.2 Vulnerability component related

Vulnerability can be defined as follows:

$$\text{Vulnerability} = \text{Exposure to risk} + \text{Inability to cope} \quad (2)$$

However, if the framework for risk (1) is used, the definition of vulnerability should simply be inability to cope with hazard since exposure is treated separately. Füssel [5] reviewed the range of definitions of vulnerability and argued that continued plurality would become a hindrance in interdisciplinary research. A common definition of vulnerability is much needed to advance the understanding of vulnerability, yet reaching consensus is challenging. As a matter of fact, some scholars have argued that previous attempts to develop a shared vulnerability framework were superficial [6, 7].

O'Brien et al. [8] presented two dominant interpretations of vulnerability, which they refer to as outcome vulnerability and contextual vulnerability. Outcome vulnerability is considered as the residual exposure to impacts of climatic changes after adaptation responses have been factored in. Studies following this interpretation often take a sectoral view, looking at which/where is likely to be worst affected. Contextual vulnerability deals dynamically with the institutional, biophysical, socioeconomic, and technological conditions that affect the extent of exposure to climate changes and the ways in which those exposed can respond. Studies following this interpretation often take a more multidimensional view in a local setting, looking at how and why groups are affected differently in the context of other changes happening simultaneously. It is, therefore, more suitable to interdisciplinary and transdisciplinary studies. The present study attempts to combine outcome vulnerability and context vulnerability for the purpose of developing a more comprehensive and structured framework.

It is a two-layer structure consisting of system vulnerability (contextual vulnerability) and component vulnerability (outcome vulnerability) as shown in **Figure 3**. Factors affecting system vulnerability can be classified into four categories. (1) The social-economic-demographic category includes factors such as general risk perception, disaster insurance, medical care, GDP, and population distribution. (2) The institutional category includes planning capability, legal system and management capability, such as evacuation operations. (3) The biophysical category includes landform and land use, river basin scale, and river dynamics. Steep river channels often generate flash floods that are difficult to predict. On the other hand, mild waterways may generate much larger floods that could be more destructive if overflow occurred. (4) The engineering category includes flood defense and warning systems.

System vulnerability can be regulated by various structural measures such as levee and retarding basin construction and nonstructural measures such as flood hazard mapping and land use regulation. The interaction of various factors results in residual system vulnerability that is then passed on to component vulnerability (or outcome vulnerability). Component vulnerability is determined by awareness, self-preparedness, community strength, and even local culture. For example, a type of old Japanese house-Mizuka as shown in **Figure 4** is a measure of self-defense. It is a two-house compound, in which one is for everyday living and another is used as shelter in case of emergency. Living in such a house reduced component vulnerability. Nevertheless, the number of such houses in Japan has been largely reduced due to various reasons, especially changes in life style and a lowering of risk awareness.

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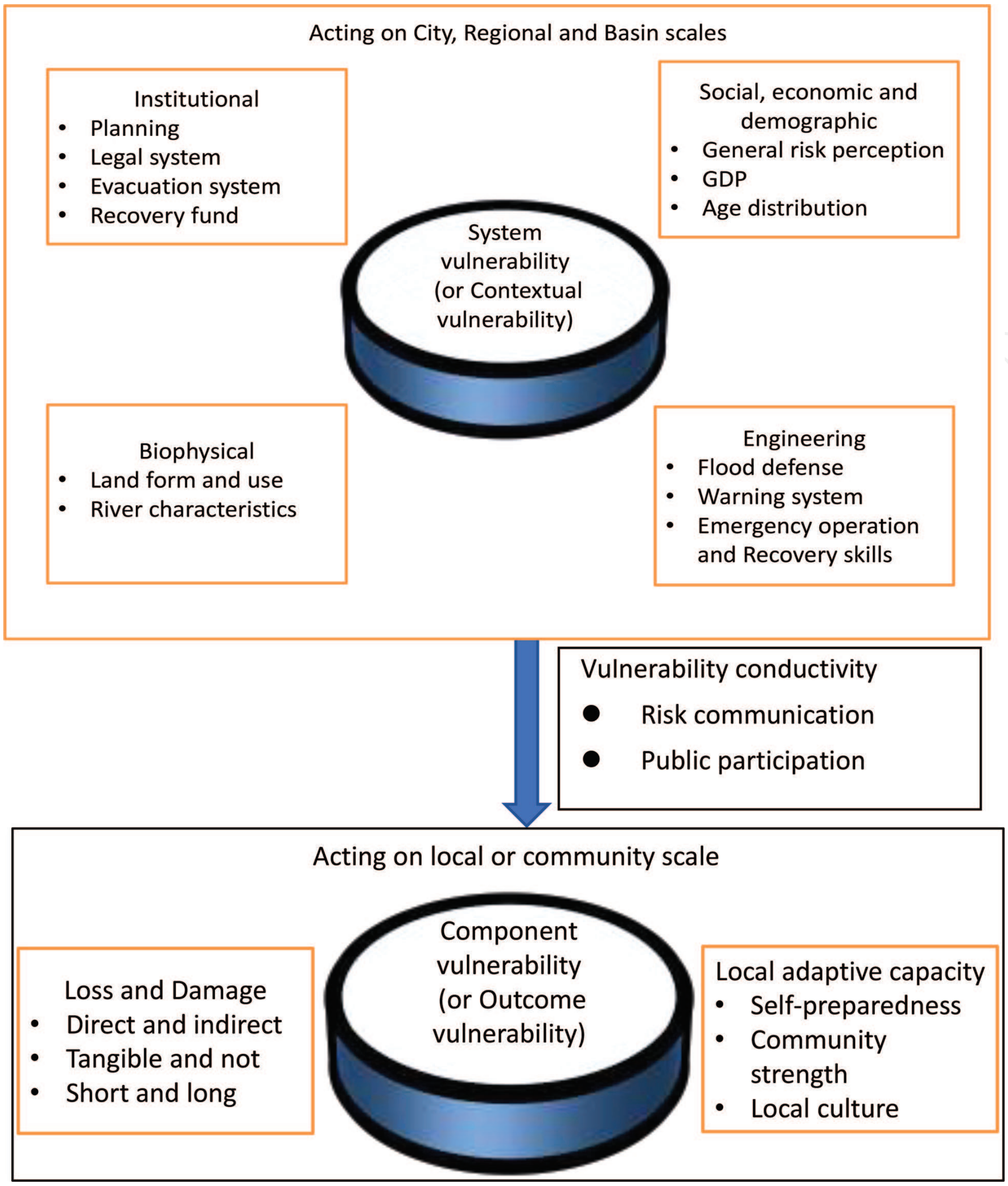

Figure 3.
A two-layer framework for vulnerability.

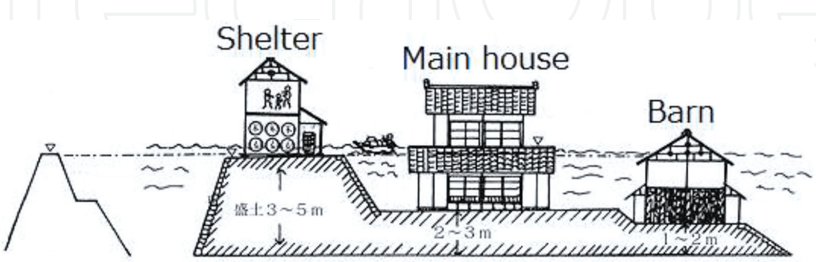

Figure 4.
A self-prepared traditional house in Japan-Mizuka.

System vulnerability acts at city, regional, or river basin scale, while component vulnerability acts at individual or community scale. The degree of passage from system to component vulnerability is termed as vulnerability conductivity hereafter. It depends upon risk communication and public participation. Risk communication is the exchange of information and opinions, and establishment of an effective dialog, among those responsible for assessing, minimizing, and regulating risks and those who may be affected by the outcomes of those risks. This is the first attempt to incorporate risk communication into a vulnerability framework and to place one of its roles in the linkage between contextual and outcomes vulnerability.

Flood disasters may cause extensive loss of life and property damage, which is essentially an anthropogenic phenomenon with social roots. However, the dimension of loss and damage has been less focused on vulnerability framing so far. A conventional framework to address loss and damage is the C × L framework as below:

$$\text{Risk} = \text{Consequence} \times \text{Likelihood} \tag{3}$$

where (i) likelihood is the probability of occurrence of an impact that affects the environment and (ii) consequence is the social and environmental impact if an event occurs.

This framework combines the scores from the qualitative or semiquantitative ratings of consequence and the likelihood that a specific consequence will occur to generate a risk score and risk rating. Although this risk framework takes into consideration the consequence of an event, it is not suitable for conducting integrated risk and vulnerability analyses. To incorporate loss and damage into the framework (1), vulnerability should be redefined as:

$$\text{Vulnerability} = \text{Inability to cope} \times \text{Potential consequence (loss and damage)} \tag{4}$$

The logic to include loss and damage in vulnerability is justifiable. If the level of impact upon an individual or community is low, then this individual or community is not truly vulnerable although they may not able to prevent certain consequences from happening. Accordingly, the two-layer framework includes loss and damage as already depicted in **Figure 2**.

Following this vulnerability framework, a policy that is different from the conventional can be proposed as below.

Conventional flood countermeasures have focused on preventing flood waters from reaching populated areas such that blocking may be considered a keyword to describe the concept of conventional flood countermeasures. However, such a zero-risk approach has been shown to be in vain, especially in urban areas. In urban areas, in addition to the problems of asset concentration and surface imperviousness, complex urban structures may affect the behavior of flood waters in the case of inundation. Either intentionally or by chance, roads, railroads, and buildings may function as barriers to keep flood waters from spreading to a wider area [9]. Consequently, urban flooding may be characterized as being confined and deep. It is well documented that the degree of fatality and direct economic cost of flooding is proportional to inundation depth [10]. Therefore, redesigning urban form to transform confined and deep flooding to wide and shallow flooding is a way to reduce vulnerability if the prevention of inundation is not totally avoidable. The concept can be rephrased as "managing flood waters up to your knees". Policy supporting such a concept can be termed flood sharing. How it can be implemented is a question to be answered.

An important driver of vulnerability reduction is better planning. Poorly planned and managed urbanization leads to growing flood hazard due to unsuitable land use change and increasing flood vulnerability due to development in flood-prone areas and overpopulation of such areas. As shown in **Figure 5**, river flood management planning in Japan starts with setting up a planning scale, which is the level of

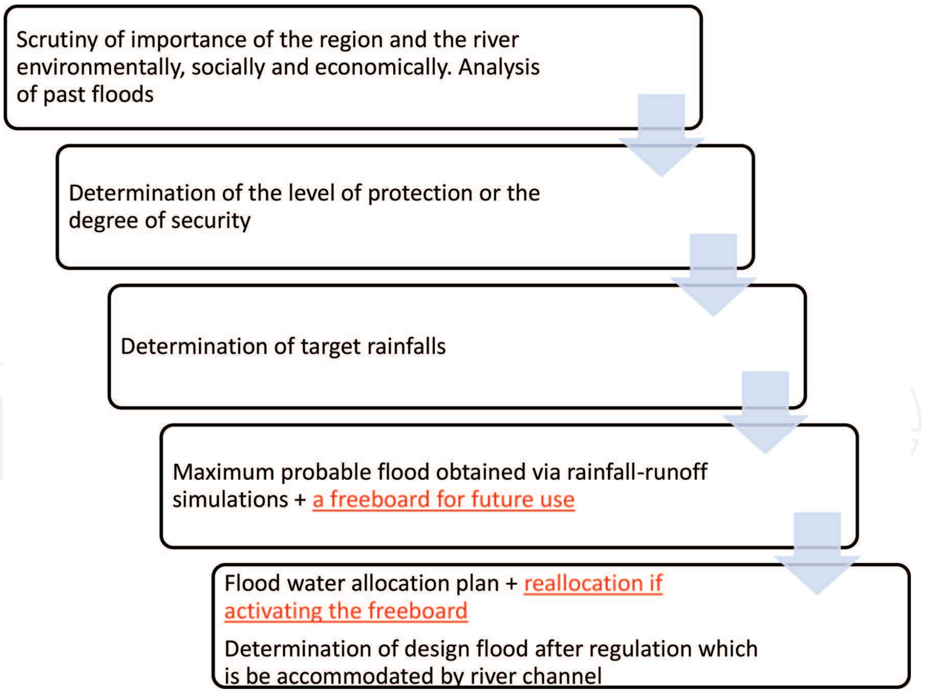

Figure 5.
Procedure of flood management planning in Japan and a proposed modification (marked with red color and underline).

safety against flood disasters to be provided in the area of concern. The next step is to select a number of target rainfalls for the planning site based on rainfall and historical flood records. Then, by performing rainfall-runoff simulations, a flood hydrograph can be determined as the management target, which is termed as either design flood without regulation or maximum probable flood. Once the maximum probable flood is estimated, allocation of flood water by dam, retarding basin, and river channel will be determined to safely convey flood water to its destination. In this planning procedure, however, the increase of maximum probable flood due to future urbanization is not directly considered. The increase in the total volume of the direct runoff is also not taken into consideration in dam and retarding basin planning. In addition, urban development planners often neglect, or are not aware of, the possibility that development may partially invalidate the river flood management design in operation in the absence of sound development planning. The fact that the maximum probable flood would vary with significant changes in land use, resulting in an increase in peak flow in a river channel, has been given less attention by urban planners in planning development of housing projects along waterways. What is often observed is that countermeasures were being taken to reduce urbanization-induced flood risk years or decades after large-scale urban development, especially after experiencing serious flood disasters. Wording differently, approaches so far have often been reactive, not proactive. Therefore, a key principle of Low Impact Development or of a Sponge City should be that no significant increase in maximum probable flood results from the process of urban development. In Japan, the Act on Countermeasures against Flood Damage of Specified Rivers Running across Cities was put into effect in 2005. According to this law, any urban development with an area larger than 1000 m^2 should not cause any increase in surface runoff. If any increase is likely, permission from the competent authority is required. This law was first applied to the Tsurumi River basin since 2006 and currently implemented in seven river basins across Japan. However, monitoring studies on change of surface runoff in the seven targeted river basins are limited. The overall effectiveness of this regulation has not been validated. **Figure 6** shows where waterlogging occurred

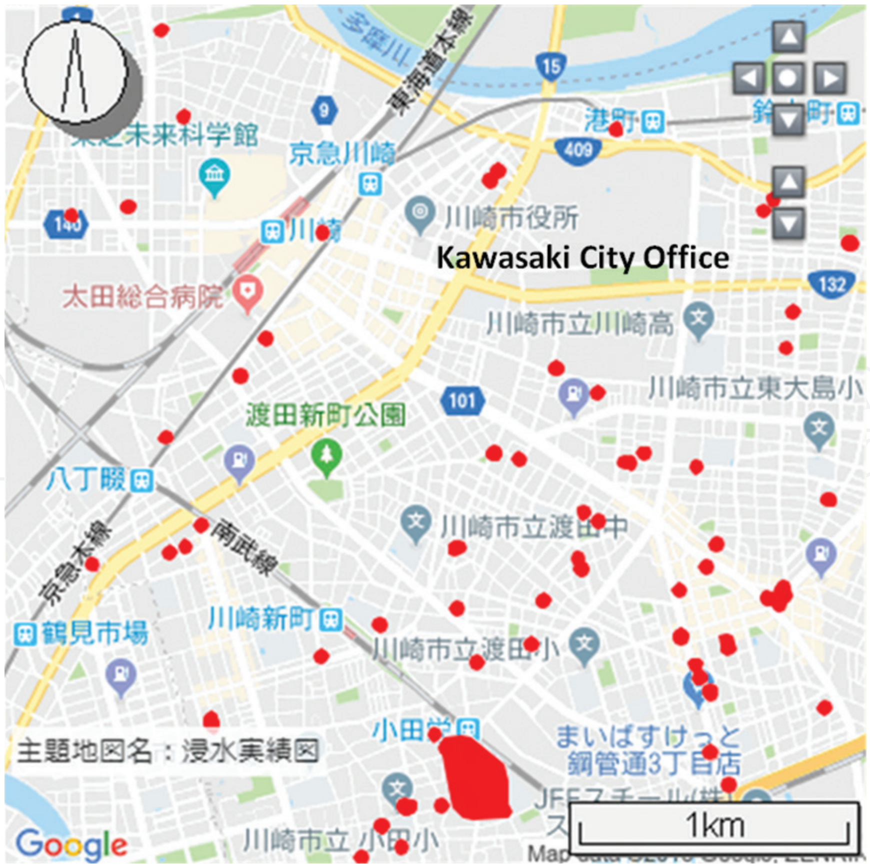

Figure 6.
Locations of waterlogging (red dot) occurred in Kawasaki City during the period of 2008–2017 (source: Kawasaki City).

during the period of 2008–2017 in Kawasaki City, which is part of the Tsurumi River basin. **Figure 7** shows where waterlogging occurred during the period of 2006–2010 in Machida City, which is also part of the Tsurumi River basin. Although 3300 storage facilities have been installed in the river basin, inundation is still a frequent visitor to the region. Besides, the waterlogging locations in Kawasaki City are more or less uniformly distributed, while the waterlogging in Machida City mainly occurred along its administrative boundary on the west side. Such a difference in distribution of vulnerable locations may be viewed as one aspect of system vulnerability.

A fundamental issue in implementing this law is that it has not been directly linked to the river flood management planning procedure. To strike a good balance between flood risk reduction and economic development, the present study proposes a new planning scheme as shown in **Figure 5** with red color and underline. For new or redevelopment, the possibility of increasing maximum probable flood should be examined. If it is not possible to deal with the increase in maximum probable flood, the Act on Countermeasures against Flood Damage of Specified Rivers Running across Cities must be strictly implemented. If additional amounts of flood waters can be handled through reallocation such as constructing new or expanding the capacities of existing storage facilities, or by in-channel engineering works such as excavation, then the law can be executed to control the total amount of increase of surface runoff while having a priority setting to give permissions to economically important development projects.

2.3 Exposure component related

In cities like Tokyo, flood waters stay on streets for a few hours or a few days at most if inundation occurs. In other places such as Bangkok, however, flood waters

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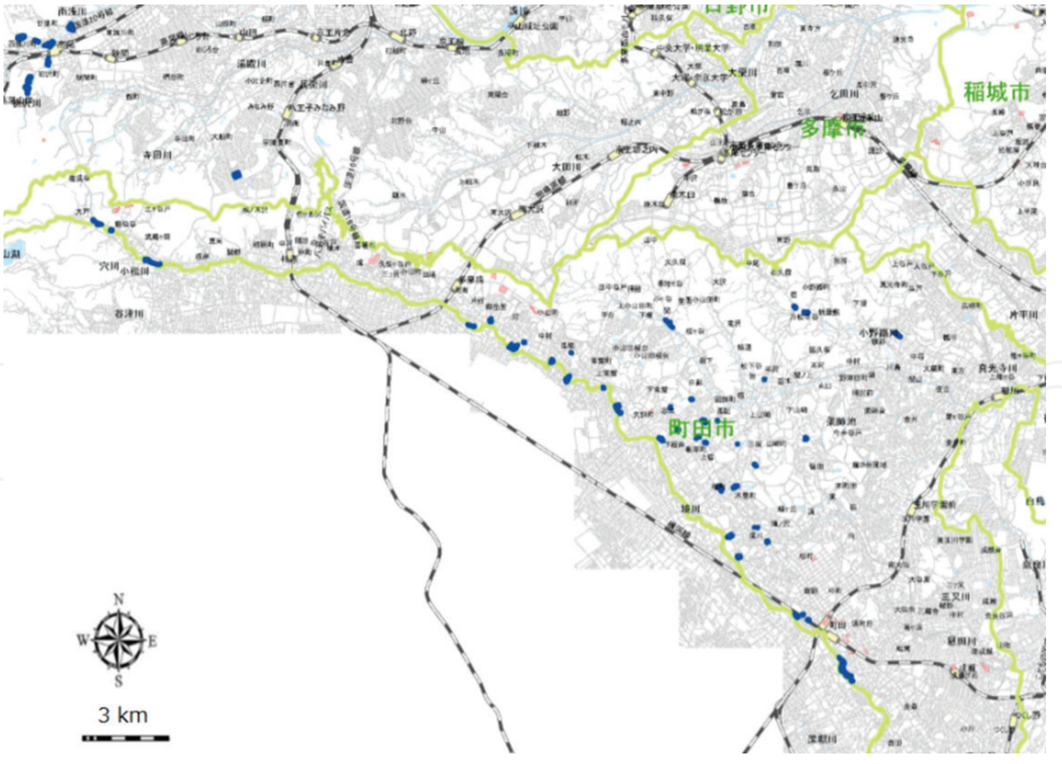

Figure 7.
Locations of waterlogging (blue dot) occurred in Machida City during the period of 2006–2010 (source: Machida City).

may stay on streets for more than 2 months due to the city's topography and insufficient drainage capacity. In Thailand, the flood damage to Bangkok and five adjoining provinces in 1983 was estimated by the National Statistical Office to be billions of Bath with the bulk of the damage shouldered by the private sector. A study by Tang et al. indicated that flood depth and flood duration were significant factors explaining flood damage in the residential and industrial areas [11].

In view of such a difference in flood water residence time, the duration of inundation should be factored into exposure component, the longer the duration, the higher the level of exposure. Adding such a temporal factor to vulnerability framework will certainly lead to better planning for vulnerability reduction and smooth emergency response. It is also related to disaster insurance. To protect buildings that are constructed in flood-prone hazard areas from damage caused by flood forces, the National Flood Insurance Program (NFIP) in the United States requires that all construction below the base flood elevation must consist of flood damage-resistant building materials [12, 13]. What constitutes flood damage-resistant building materials is indeed duration dependent. The impact of duration is a much less explored research area and is envisioned to gain more attention in the near future.

3. Eco-DRR in Japan

Ecosystem-based disaster risk reduction (Eco-DRR) is a relatively new concept to reduce the risk of being exposed to natural hazards by avoiding development in disaster-prone areas or by using natural systems as a way to buffer the worst impacts of natural hazards, maintain the resilience of natural ecosystems and their ecosystem services, and help people and communities adapt to changing conditions [14, 15]. The core thinking of Eco-DRR is based on the realization that disasters cause massive damage to the environment, while degraded environments exacerbate disaster impacts and responding to disasters often leads to additional environmental impacts. Well-managed ecosystems, such as wetlands, forests, and coastal systems, act as natural infrastructure, reducing physical exposure to many hazards and increasing socioeconomic resilience of people. For example, mangroves and seagrass beds can dissipate the destructive energy of storm surge and Tsunami and prevent coastal erosion while supporting fishing and tourism activities and storing high amounts of carbon. Therefore, Eco-DRR is also aimed at reducing the vulnerability of society and establishing disaster-resilient communities.

Japan has a tradition of using ecosystems for disaster mitigation such as maintaining forests to prevent soil erosion, planting trees along its coast to reduce wind-related disasters, and utilizing paddy fields to store flood waters temporarily. Since 2012, Eco-DRR has been incorporated into national policies and planning of the Japanese government. The Basic Act for National resilience, enacted in 2013, is aimed at taking advantage of regional ecosystem-based functions to prevent and reduce disasters. Following this Act, Fundamental Plan for National Resilience was established to promote the use of ecosystem-based disaster reduction approaches and assessment of functions of Eco-DRR initiatives provided during nondisaster times. The National Spatial Strategy and the National Land Use Plan, approved in 2015, also called for the promotion of disaster management using natural ecosystems. Furthermore, Japan's Forest Law requires that Disaster Risk Management (DRM) forests should be planted along the coast to prevent damages from blown sand and salt, high tides, and tsunamis. Under such strong policy drivers, a question is "does it work?"

On March 11, 2011, the Great East Japan Earthquake occurred and trigged a major Tsunami. Consequently, the Tohoku area of Japan was so badly hit Tsunami. In total, this disaster caused more than 15,000 deaths, 2800 missing, and approximately 300,000 people being evacuated [16]. Among the disaster-stricken areas, Miyagi Prefecture suffered the most in terms of fatalities and infrastructure damage. Before the disaster, there were 200- to 400-m-wide pine forests along the Sendai Plains of Miyagi Prefecture having protected the area for the past four centuries. Nevertheless, the forest failed to stop the intrusion of the Tsunami. The coastline of Rikuzentakata City, Iwate Prefecture, was also very famous for its 2-km-long and 200-m-wide pine trees as shown in **Figure 8**. Again, the forest was completely destroyed except for one tree after the 3/11 Tsunami. There is no doubt that the forest along the coast of Tohoku region did reduce the energy of Tsunami. Although the forest was destroyed during the disaster, without it, fatalities and property damage would undoubtedly have been much greater. The question is how to quantify its effectiveness in relation to Tsunami height. It is not difficult to imagine that a coastal forest is effective to a Tsunami with low wave height. The information needed is the threshold of wave height above which a coast forest may fail to dissipate the energy of Tsunamis significantly. Koshimizu [17] pointed out that coastal forests could be rendered useless by liquefaction, but no countermeasures had been discussed. Besides, it should not be forgotten that a fallen tree being moved by a Tsunami can kill people and damage houses.

An interesting phenomenon was observed in Ishinomaki City, Iwate Prefecture. Along a portion of the Watanoha coast, the levee was lightly damaged, but the residential area behind was devastated as can be clearly seen in **Figure 9**. The levee height before the disaster was 4 m, and the Tsunami height in Ishinomaki was more than 8.6 m according to Japan Meteorology Agency. This implies that the Tsunami overtopped the levee without much energy dissipation. Otherwise, the levee would have been badly damaged. The same phenomenon may also apply to coastal forests if the height of a Tsunami is much higher than the height of the forest. After the disaster, the Japanese Government decided to invest ¥59 billion to restore 3660 hectares of trees in Tohoku, which were destroyed by the Tsunami [18]. However, as can be seen from Google Earth, the restoration of coastal forests has not produced

Figure 8.
Coast forest before and after the Tsunami disaster on March 11, 2011.

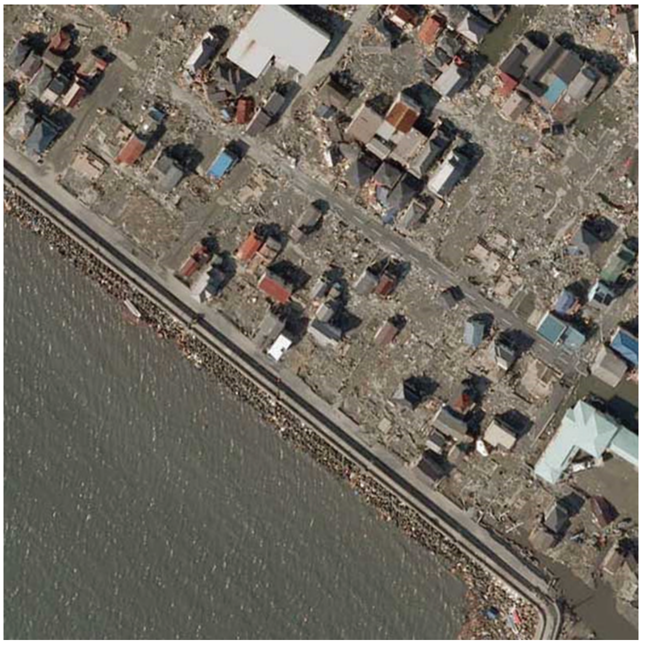

Figure 9.
Devastated residential area behind a coastal levee.

any visible progress. Instead of costal forest, concrete levee is expanding along the coast as shown in **Figure 10**. This was also confirmed by author's field survey conducted in July 2018. Despite legislative development with regard to Eco-DRR in Japan, the implementation appears not straightforward. A multilayered defense system combining Eco-DRR measures with conventional concrete-based measures may deserve serious discussion or even debate.

Another case, which has been advocated as an example of Eco-DRR, is the Kabukuri-numa wetland in Osaki City, Miyagi Prefecture, Japan. In the 1970s, it was merely used as a flood-retarding basin. Large-scale dredging of the wetland was planned to increase its flood regulation capacity in 1996. However, in response to environmental concerns, the dredging plan was withdrawn. Instead, the area of the Kabukuri-numa wetland was expanded by transforming surrounding fallow farmland to wetland to meet the flood regulation demand. Furthermore, water was retained in surrounding paddies during the winter so as to function as semi-natural, but still important, habitat for wetland-dependent wildlife. In 2005, the Kabukuri-numa wetland and surrounding paddy fields were registered together as a Ramsar wetland site [19, 20]. As a result of this wetland expansion, a large number of waterfowls overwinter in Kabukuri-numa, eating fallen grain and weeds in the

Figure 10.
Current situation of defense construction along the Tsunami-hit coast.

flooded paddy fields. The bird droppings, which are rich in phosphate, function as high-quality natural fertilizers for rice and enrich the soil. Rice cultivated under such an environment is branded as such and can be sold at a higher-than-average price. In addition, the large number of overwintering birds attracts a large number of tourists every winter. Although the ecosystem services of the Kabukuri-numa wetland during nondisaster times have been well demonstrated, its flood regulation capability has not been tested since there have been no large-scale floods in recent decades. In addition, there are concerns over the water quality of the wetland due to the large number and high concentration of birds. Bird droppings entering paddy fields may contribute to rice production but may also impact the water quality of adjacent wetlands if entering into its water body. As a matter of fact, water quality testing in the Kabukuri-numa wetland by the author of this chapter indicated that the water body is already eutrophic. How to make this Eco-DRR initiative sustainable is a question to be answered.

4. Conclusion

The present work highlights a number of subjects in the arena of flood risk management that deserve further in-depth research, as summarized below.

In terms of flood hazard identification, flood peak timing and multipeak hydrographs should be given more attention.

Due to the existence of various definitions and interpretations of vulnerability, there is a need to combine or group some of the notions, if the integration of all is impossible, for the sake of a better and deeper understanding of what really constitutes vulnerability. Following this line of thinking, a new two-layer framework of vulnerability is proposed, integrating existing concepts to a certain extent. This new framework may help develop new approaches to vulnerability reduction, with new concepts such as flood sharing.

This new framework also suggests that inundation duration should be included in the analysis of exposure.

Eco-DRR is an emerging approach to achieving both flood risk management and environmental conservation and may contribute to local economies as well. However, more cases of Eco-DRR across the world should be collected and analyzed from various angles in order to quantify its effectiveness and promote best practice. In Japan, Eco-DRR is advanced in terms of the legal framework supporting it, but there is great uncertainty in terms of its performance. Innovation is indispensable in reaching a new stage of flood risk management.

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Conflict of interest

The authors declare no conflict of interest.

Author details

Guangwei Huang
Graduate School of Global Environmental Studies, Sophia University, Tokyo, Japan

*Address all correspondence to: huang@genv.sophia.ac.jp

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